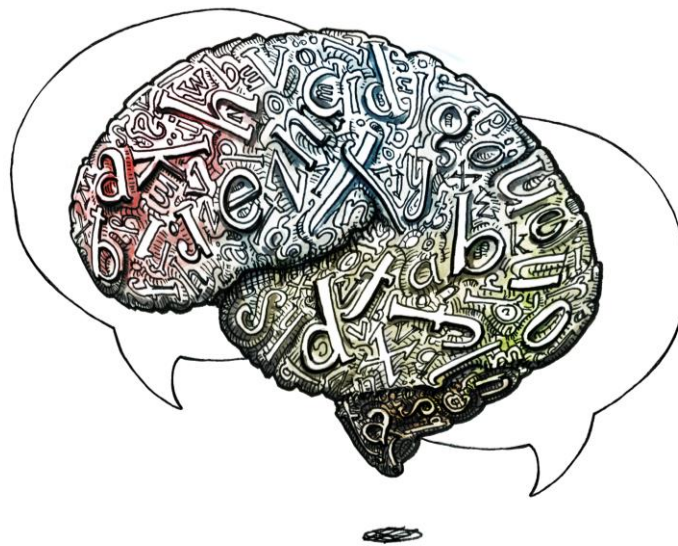


# NEUROCOGNITIVE MECHANISMS OF LANGUAGE PROCESSING AND CONTROL IN EARLY BILINGUALS AND LATE LANGUAGE LEARNERS

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# Contents

<b>Abstract .....</b>	<b>4</b>
<b>Tiivistelmä .....</b>	<b>6</b>
<b>Acknowledgements .....</b>	<b>8</b>
<b>List of original publications .....</b>	<b>10</b>
<b>Abbreviations .....</b>	<b>11</b>
<b>1. Introduction .....</b>	<b>12</b>
<b>1.1 Definitions of bilingualism .....</b>	<b>12</b>
<b>1.2 EEG and MEG.....</b>	<b>14</b>
<b>1.3. Semantic processing in L1 and L2 .....</b>	<b>15</b>
1.3.1 N400(m) as in index of semantic processing .....	16
1.3.2 Behavioural studies on lexical-semantic processing: the bilingual disadvantage .....	17
<b>1.4. Language switching and language control .....</b>	<b>19</b>
1.4.1 N400(m) as a tool to measure language control in perception .....	21
<b>2. Aims of the the thesis .....</b>	<b>23</b>
<b>3. Methods .....</b>	<b>24</b>
<b>3.1 Participants .....</b>	<b>24</b>
<b>3.2 Questionnaires .....</b>	<b>26</b>
<b>3.3 Stimuli .....</b>	<b>26</b>
<b>3.4 Experimental procedures.....</b>	<b>29</b>
<b>3.5 Data acquisition and analysis.....</b>	<b>30</b>
<b>3.6 Statistical analysis.....</b>	<b>31</b>
<b>4. Results and Discussion.....</b>	<b>34</b>
<b>4.1. Study I: The effect of switches to L1 during semantically congruent and incongruent sentences.....</b>	<b>34</b>
<b>4.2 Study II: Language control mechanisms during language switching in trilinguals .....</b>	<b>37</b>
<b>4.3 Study III: Speed and accuracy of word recognition in early bilinguals and late learners compared to monolinguals .....</b>	<b>40</b>
<b>5. General discussion .....</b>	<b>43</b>
<b>5.1. Semantic and lexical processing in L1 vs. L2 .....</b>	<b>43</b>
<b>5.2 Control mechanisms for native and later-learned languages .....</b>	<b>46</b>
<b>5.3 Limitations and future directions .....</b>	<b>49</b>
<b>6. Conclusions .....</b>	<b>51</b>
<b>References .....</b>	<b>53</b>

## **Abstract**

The ability to speak more than one language is nowadays commonly the rule, rather than the exception. Many forms of bilingualism exist, varying from early bilingualism in which more than one language is acquired in early childhood, to late bilingualism, where another language is not learned until adulthood. Although a large amount of research has been devoted to the question of how these multiple languages are processed and controlled, conclusive answers have not yet been given. Especially regarding language perception, there have not been many studies to investigate whether active language control is needed in case one does not need to actively select and produce lexical items.

The first aim of this thesis was thus to study language control during language perception in more detail, and secondly, to investigate to what extent lexical and semantic processing differs between early-acquired and later-learned languages. The first study examines the effects of language switching on semantic processing (Study I). The second study focuses on trilingual language switching, taking a closer look at the control mechanisms that play a role in this (Study II), while the third study investigates whether early bilingualism leads to possible disadvantages or qualitatively different lexical processing (Study III).

This PhD work used various research methods, namely magnetoencephalography (MEG) and encephalography (EEG), as well as behavioural methods and extensive language background questionnaires. The findings of this thesis suggest that language control differs according to the strength of the language network. Even though language switching from L2 to L1 is costly at the neurocognitive level, evidenced by enhanced N400 effects, semantic processing remains unhindered (Study I). However, there is no apparent cost of switching between native languages (Study II) whereas an increase in N400(m) is seen after switches from a later-learned language to the native one (Study I and II). Furthermore, the acquisition of two languages at an early age does not notably affect the speed or accuracy with which lexical processing in either language occurs (Study III), as early bilinguals performed worse on only 1 out of 12 data sets, compared to monolingually raised native speakers.

Taken together, the results of this thesis show that bilingual language processing and control is modulated by various language background factors, such as the experience and skills in each particular language, as well as the frequency of use. Provided that the language network is sufficiently strong, lexical and semantic processing of a second language will look similar to that of monolingual native speakers. This thesis proposes that bilinguals use their full linguistic knowledge to make sense of the linguistic input around them, while they are at the same time constantly aware of language membership.

## Tiivistelmä

Kyky puhua useampaa kuin yhtä kieltä on nykyään pikemminkin sääntö kuin poikkeus. Kaksikielisyys ilmenee monissa muodoissa varhaisesta kaksikielisydestä, jossa useampi kuin yksi kieli opitaan varhaislapsuudessa, myöhäiseen kaksikielisyyteen, jossa toista kieltä ei opita ennen aikuisikää. Monia tutkimuksia on omistettu sen tulkitsemiseen, miten näitä eri kieliä käsitellään ja kontrolloidaan. Ratkaisevia tuloksia näistä ei ole kuitenkaan vielä saatu. Erityisesti kielen havainnoinnin osalta ei ole vielä riittävästi tutkimusta siitä, tarvitaanko aktiivisia kielen hallintaprosesseja sellaisessa tapauksessa, jossa ei ole tarvetta aktiivisesti valita ja tuottaa sanoja.

Tämän väitöskirjan tarkoituksena oli tutkia yksityiskohtaisemmin kielenhallintaprosesseja kielen havainnoinnin aikana, sekä selvittää, missä laajuudessa leksikaalinen ja semanttinen käsittely poikkeavat aikaisin opittujen ja myöhemmin opeteltujen kielten välillä. Ensimmäinen tutkimus tarkastelee kielen vaihtamisen vaikutuksia semanttiseen prosessointiin (Tutkimus I). Toinen tutkimus keskittyy kolmikieliseen kielen vaihtamiseen, tarkastellen lähemmin tässä tapauksessa vaikuttavia hallintamekanismeja (Tutkimus II). Kolmas tutkimus puolestaan tarkastelee, johtaako varhaisiän kaksikielisyys mahdollisesti haittoihin tai leksikaalisen käsittelyn poikkeavuuksiin verrattuna yksikielisyyteen (Tutkimus III).

Tutkimuksessa käytettiin useita tutkimusmenetelmiä, kuten magnetoenkefalografiaa (MEG), elektroenkefalografiaa (EEG), käyttäytymistä mittaavia menetelmiä, sekä laajaa kielellisten taustatietojen kyselyä. Tähän väitöskirjaan tehtyjen tutkimusten löydökset viittaavat siihen, että tarvittavien hallintaprosessien suuruus vaihtelee kielellisen verkoston vahvuuden mukaan. Vaikka kielen vaihtaminen toisen ja ensimmäisen kielen välillä on vaativaa, mihin havaittu N400-efekti viittaa, merkityksen käsittelyä se ei vaikeuta (Tutkimus I). Äidinkielen välillä ei kuitenkaan ollut havaittavissa tällaista kielen vaihtamisen kustannusta (Tutkimus II), kun taas N400m-vasteen kasvua oli havaittavissa myöhemmin opitun kielen ja äidinkielen vaihtojen välillä (Tutkimukset I ja II). Lisäksi havaittiin, että kahden kielen oppiminen varhain ei vaikuta merkittävästi kummankaan kielen leksikaalisen prosessoinnin

nopeuteen tai tarkkuuteen (Tutkimus III), sillä varhaisten kaksikielisten suoritus oli huonompi vain yhdessä tapauksessa 12 osa-aineistosta, verrattaessa yksikielisessä ympäristössä kasvaneisiin äidinkielen puhujiin.

Yhteenvetona tämä väitöskirja osoittaa, että kaksikielisen henkilön kielen prosessointikykyyn ja hallintaan vaikuttavat monet taustatekijät, kuten altistus kielelle, kielitaito ja kielen käyttöaste kussakin kielessä. Kun kielen käsittelyn verkosto on riittävän vahva, leksikaalinen ja semanttinen prosessointi ovat samankaltaisia kuin yhtä kieltä äidinkielenään puhuvilla. Tämä väitöskirja esittää, että kaksikieliset käyttävät koko kielellistä tietoaan ymmärtääkseen heitä ympäröivää kielellistä sisältöä, ollen samalla jatkuvasti tietoisia siitä, mistä kielestä on milloinkin kyse.

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## List of original publications

This thesis is based on the following publications:

- I Hut, S.C.A., & Leminen, A. (2017). Shaving Bridges and Tuning Kitaraa: The Effect of Language Switching on Semantic Processing. *Frontiers in Psychology*, 8: 1438.
- II Hut, S.C.A., Helenius, P., Leminen, A., Mäkelä, J. P., & Lehtonen, M. (2017). Language control mechanisms differ for native languages: Neuromagnetic evidence from trilingual language switching. *Neuropsychologia*, 107, 108-120.
- III Hut, S.C.A., Wikman, P. & Lehtonen, M. (Submitted). Are there disadvantages in word recognition in early bilinguals? The effect of language exposure.

The publications are referred to in the text by their Roman numerals. The articles are printed with the permission of the copyright holders. The thesis also includes unpublished material.

## Author contribution

- I Hut designed the study and the stimuli, collected the data, pre-processed and analysed the data, and wrote the manuscript.
- II Hut designed the study and the stimuli, collected the data, pre-processed and analysed the data, and wrote the manuscript.
- III Hut partially collected the data, digitalised and analysed the data, and wrote the manuscript.

## Abbreviations

ANOVA	analysis of variance
AoA	age of acquisition
CEFR	Common European Framework Reference
EEG	electroencephalography
EOG	electro-oculogram
ERP	event-related potential
IFG	inferior frontal gyrus
ISI	inter-stimulus interval
L1	first language
L2	second language
LMM	linear mixed model
LORETA	low resolution brain electromagnetic tomography
MNE	minimum-norm estimation
N400	negative ERP peaking at 400 ms
N400m	N400, magnetically recorded
n.s.	non-significant
MEG	magnetoencephalography
ms	millisecond
ROI	region of interest
RHM	Revised Hierarchical Model
SOA	stimulus onset asynchrony
SD	standard deviation
STG	superior temporal gyrus
SVO	subject-verb-object

# 1. Introduction

Worldwide, there are close to 7000 languages in use (Simons & Fennig, 2017). All of these languages have their own specific features, varying in their vocabulary, syntactic structure, set of phonemes, and sometimes in their writing system as well. Yet, there is one thing that all of these languages have in common: they facilitate human communication. In some parts of the world it is not unusual to only speak one language throughout life, such as in the United States. In contrast, in traditionally multilingual countries such as India, people may use multiple languages every day and switch between them depending on the conversational setting they find themselves in. Due to the continuously increasing globalisation, bilingualism is nowadays becoming more commonly the rule, rather than the exception, even in countries that have traditionally only used one official language.

Bilingual speakers are faced with a challenging task every time they use one of their languages. Even if they may not be consciously aware of it, they need to be able to distinguish between their languages and fend off interference from the language that is not in active use. If not, keeping the multiple languages apart and using them in separation, would be nearly impossible. Depending on the strength or dominance of the language, the need for active language control may differ.

The control and processing of native and later-learned languages is the main topic of this doctoral thesis. Whereas earlier research has often investigated the role of language control during language *production*, the studies in this thesis focus exclusively on language processing and language control during language *perception*.

## 1.1. Definitions of bilingualism

Early definitions of bilingualism have generally been fairly narrow, only regarding people with a more or less equal mastery of their languages as true bilingual speakers. Bloomfield, for instance, defined bilingualism as “the native-like control of two languages” (Bloomfield, 1933: 56). The definition by Thiery a few decades later still resembles the idea that a bilingual speaker is, roughly said,

two monolingual speakers in one: “A true bilingual is someone who is taken to be one of themselves by the members of two different linguistic communities [...]” (Thiery, 1978: 46). The past few generations have seen a shift in the notion of what constitutes a true bilingual. Nowadays, a popular definition is that by Grosjean, who simply states that a bilingual is someone “who uses two or more languages in their everyday life” (Grosjean, 2010), although full consensus over its definition has not yet been reached (Paradis, 2004).

It may therefore be more useful to discuss the many characteristics that describe a bilingual speaker, and how these characteristics may vary between bilinguals. Different factors play a role in determining the degree of bilingualism, such as the age at which a second language (L2) is learned (age of acquisition; AoA), the frequency with which each of the languages is used, or the proficiency that has been attained in each of the languages.

One of the distinctions that can be made based on the AoA, is the one between *simultaneous* bilingualism, *early successive or sequential* bilingualism and *late bilingualism*. Whereas early bilingualism usually refers to a situation in which the languages have been acquired in early childhood, the term *simultaneous* refers to the fact that they have been acquired at the same time, while in *successive or sequential* bilingualism, the acquisition of one language preceded the acquisition of the other. Finally, *late bilingualism* indicates that a second language is only learned after childhood (e.g. Lambert, 1985; McLaughlin, 1984; Myers-Scotton, 2008). In this light, the literature also often distinguishes between *acquiring* and *learning* a second language. The more subconscious process of learning a language at a young age is often coined ‘acquisition’, whereas ‘learning’ is often describes as a process where language learners rely on more conscious knowledge as a result of formal teaching (Krashen & Terrell, 1983).

Language *dominance*, however, usually refers to the relative strength of one language compared to the other (Albert & Obler, 1978). A definition of language dominance could be based on language proficiency (Gathercole & Thomas, 2009), but also the exposure to the language may determine language dominance (Grosjean, 2010). When proficiency in the languages is of a more or less equal level or when the languages are used to a roughly similar extent, the term *balanced* bilingualism usually surfaces (Hernandéz-Chávez et al., 2013).

## 1.2. EEG and MEG

In order to study the way languages are processed and controlled, the use of neuroimaging methods provides valuable insights. In this PhD work, both EEG and MEG have been used.

Electroencephalography (EEG) is a non-invasive electrophysiological method that allows the measurement of electrical activity of the brain via electrodes along the scalp. EEG activity is caused by the summation of the synchronous postsynaptic activity of a large population of neurons with a similar spatial orientation, mostly made up of cortical pyramidal cells (Luck, 2014). When EEG responses are time-locked to the occurrence of a stimulus (an event), they are referred to as event-related potentials (ERPs) (Luck, 2014). Several characteristics of ERPs can be studied, such as the latency, the amplitude and the topography of the components. Changes related to the physical stimulus (visual, auditory etc.) and the cognitive state of the subject may result in modulations of the ERPs (Näätänen & Winkler, 1999).

The temporal resolution of EEG is very high, making it a very suitable method to study ongoing cognitive processes on a millisecond scale, and EEG provides a direct benefit compared to several other neuroimaging methods. However, the spatial localisation of neural activity is challenging in EEG, due to distortions caused by the skull (Cohen and Cuffin, 1983). Spatial localisations can be obtained more accurately with MEG.

Magnetoencephalography (MEG) is, like EEG, a noninvasive method with an excellent temporal resolution for detecting ongoing neural activity (Cohen, 1972). MEG records the magnetic field that is generated by electrical activity of large neural populations, using radio-frequency Superconducting Quantum Interference Devices (SQUIDS: Silver and Zimmerman, 1965; Zimmerman et al. 1970) that are located in a helmet, placed over the head's surface. The SQUID sensor array consists of triplets of one magnetometer and two planar gradiometers, which nowadays result in a total of 306 channels (Hari & Salmelin, 2012). One of the major advantages of MEG as compared to EEG, is the improved accuracy with which neural activity can be localised, as magnetic fields are less distorted by the skull (Cohen and Cuffin, 1983; Hämäläinen et al., 1993).

As in EEG, time-locked responses to events can be recorded, in this case referred to as event-related fields (ERFs). However, while MEG is sensitive to electric currents originating from tangentially located sources in the cortical sulci, EEG is sensitive to both radially and tangentially oriented electrical activity (depending on the lead field defined by the reference and other electrode geometry) (Nunez & Srinivasan, 2006).

In source localization, one has to take into account the inverse problem. This problem refers to the detection of the position of the current sources from electrode potentials and does not have one unique solution. Instead, the location of neural sources can be estimated via various regularization techniques and methods based on minimum norm estimates (MNE) (Grech et al., 2008), as well as low resolution electrical activity tomography (LORETA) (Grech et al., 2008; Pascual-Marqui et al., 2002).

Especially EEG has been used frequently in studies in the field of bilingualism, but in the last decade, the use of MEG has increased as well. Because of their excellent temporal resolution, they allow for detailed information on the way languages are processed and controlled.

### **1.3. Semantic processing in L1 and L2**

A large portion of bilingualism research has focused on whether language processing is different for a second language (L2) compared to the first acquired, native language (L1). This specific topic has been influenced greatly by the controversial ‘critical period’ hypothesis (Penfield & Roberts, 1959; Lenneberg, 1967), later regarded as a ‘sensitive period’, which states that language acquisition becomes much more effortful after early childhood. Especially grammatical aspects of language are often found to be troublesome for L2 learners, demonstrated by an unsystematical use of morphology or omission of morphological features (for a review, see White, 2003). Neuroimaging studies on the processing of grammar by L2 speakers frequently demonstrate that L2 speakers engage different neural networks compared to native speakers, even if they have attained a high proficiency in the language (e.g. Wartenburger et al., 2003; Ullman, 2001).

Regarding semantic processing, however, it seems that native-like processing is possible after L2 speakers have attained sufficient language proficiency and language experience (Kotz, 2001; Ullman, 2001). Yet, in early stages of L2 learning, semantic processing in L2 might still look quite different from native-like performance, both on the neural and the behavioural level (e.g. Kotz & Elston-Güttler, 2004). This could in part be due to weak links between lexical items in L2 and the conceptual system in which word meaning is stored, as described in the Revised Hierarchical Model (RHM; Kroll & Stewart, 1994). The RHM proposes that L2 learners with a lower proficiency will access the conceptual meaning of words via the lexical representations in L1. Only once proficiency is high enough, direct links between lexical representations in L2 and the conceptual system will be formed. Similarly, the convergence hypothesis (Green, 2003) proposes that as proficiency of L2 speakers increases, neural convergence with L1 speakers may be reached. A sufficiently high proficiency in L2 may thus result in semantic processing similar to native speakers of that language.

Some behavioural evidence has shown, in contrast, that even early bilinguals might not always perform on par with monolingually raised native speakers concerning word recognition and other lexical characteristics (e.g. Lehtonen et al., 2012). In the section below, these issues will be discussed in more depth.

### **1.3.1. N400(m) as an index of semantic processing**

One of the ERP components used to study semantic processing in L1 and L2 is the N400. The N400 is a monophasic, negative-going deflection that occurs between 200 and 500 ms and is usually largest over centro-parietal sites (Kutas & Federmeier, 2011). The first study to elicit the N400 effect contrasted semantically congruent and incongruent sentence endings in a reading task (Kutas & Hillyard, 1980). Incongruent target words elicited a larger N400 component, and over the next few decades, N400 paradigms have been frequently used to study semantic fit and semantic integration. In principle, any word belonging to the open-class category— nouns, verbs, adjectives – elicits an N400, but the amplitude of this component is related to the ease with which the



word can be fit into the sentence context (Brown & Hagoort, 1993; or for a review, see Kutas & Van Petten, 1994). However, the elicitation of the N400 is not purely limited to linguistic stimuli; also object, face and gesture processing, amongst others, have been shown to induce the N400 component (for a review, see Kutas & Federmeier, 2011; Lau et al., 2008).

Nevertheless, the N400 has proven to be a suitable tool for investigating semantic processes in L1 and L2 speakers, especially due to its sensitivity to factors that differ between L1 and L2 speakers, such as language proficiency, AoA or language exposure. In late bilinguals, delayed peak latencies for the N400 in response to semantic incongruities have been observed (Ardal et al., 1999; Weber-Fox & Neville, 1996; Newman et al., 2012) as well as reduced amplitudes (Ardal et al., 1999; Newman et al., 2012). The way in which late L2 learners respond to semantically correct words has also been found to be slightly different in comparison to native speakers, while the L2 learners show larger N400 amplitudes (Hahne & Friederici, 2001; Newman et al., 2012). As late bilinguals become more proficient in their L2, they show N400 responses after incongruent target words, similar to native speakers (e.g. Ojima et al., 2005). A study by Moreno and Kutas (2005) further showed that in late bilinguals, both language proficiency and age of exposure contribute to the speed of semantic analysis and semantic integration in L2, with a later onset of the N400 in the non-dominant language.

### **1.3.2. Behavioural studies on lexical-semantic processing: the bilingual disadvantage**

Numerous studies on lexical-semantic processing comparing monolinguals to early bilinguals or late bilinguals, have utilised lexical decision tasks. In a lexical decision task, the participant is asked to quickly decide whether the presented item is a real word or not (a pseudoword), usually via a button press. The automaticity of lexical processing in L2 is majorly affected by the proficiency in the language (Kotz & Elston-Güttler, 2004) and language training also leads to more skilled word recognition in L2 learners (Segalowitz & Segalowitz, 1993).

Lexical decision studies have identified many psycholinguistic variables that contribute to the reaction time or accuracy rate in response to experimental items. These include the length of a word, word frequency, word morphology (monomorphemic or inflected) and lexicality (e.g. New, 2006; Keuleers et al., 2010; Lehtonen et al., 2006). Late learners often show slower reaction times as well as increased error rates, which could be due to a lower proficiency (Harrington, 2006) or a later word AoA (Montrul & Foote, 2012). Some studies have even demonstrated that the performance of early bilinguals is different from monolinguals, even though these early bilinguals match monolinguals in language proficiency, language use and AoA. Early bilinguals have been reported to display longer reaction times, and show larger effects of frequency, lexicality and morphology as well (Ransdell & Fischler, 1987; Lehtonen & Laine, 2003; Lehtonen et al., 2006; Lehtonen et al., 2012).

Two theories account for these slower responses and differential psycholinguistic effects, also called the ‘bilingual disadvantage’. One of them is the *weaker links hypothesis*, originally developed to explain bilingual disadvantages in word production. According to this hypothesis, early bilinguals have received generally lower levels of exposure to lexical representations in both of their languages, as they grew up dividing their time between two languages. Because of the relatively lower word frequencies in each language, the links between the semantics and phonology are weaker, which ultimately leads to more effortful word retrieval (Gollan & Silverberg, 2001; Gollan et al., 2008). Another explanation for the bilingual disadvantage, the *lexical competition account*, is based on constant lexical competition between similar lexical representations that belong to each of the languages. Due to this cross-language lexical competition in bilinguals, word retrieval or recognition may be delayed in comparison to monolinguals (Gollan et al., 2008).

#### **1.4. Language switching and language control**

The question of how multiple languages are stored and managed in the brain, has been of interest to many researchers past and present. Nowadays there is a general consensus on access to language being non-selective in nature (for a

review, see Kroll et al., 2006), meaning that the languages of bilingual speakers are constantly active, even if they find themselves in situations where only one language is needed. Nevertheless, bilingual speakers seem to be able to switch between ‘language modes’ with relative ease (Gonzales & Lotto, 2013; Grosjean, 2013), ‘tune into’ a certain language after exposure to language-specific stimuli (Elston-Güttler and Gunter, 2008), or even block off their first, native language in phonological processing (Peltola et al., 2012). A recent study demonstrated that even faces can prime specific languages, although in the case that faces were associated with those of bilingual speakers, these priming effects disappeared (Woumans, 2015).

Thus, in order to maintain functional communication and use languages in separation, the bilingual speaker is in need of a system that keeps the several languages apart. One of the most influential models of language control is the Inhibitory Control model (Green, 1998), originally proposed to explain the prevention of interference especially during language production. The model suggests that active language control, i.e., control of the activation levels of the languages, is based on inhibition, i.e., suppressing a strong, dominant language during the use of a non-dominant language. In turn, when the dominant language is in use, the need to inhibit the other, weaker language is absent, as its lower activation levels result in less interference.

Evidence for the model has been provided by asymmetric switching costs, observed in studies that use language switching paradigms as a means to study ongoing language control mechanisms. Several behavioural studies on language production have shown such asymmetric switching costs, with switches to the dominant language leading to longer reaction times than switches in the other direction (Jackson et al., 2001; Meuter and Allport, 1999; Philipp et al., 2007; Tarłowski et al., 2013). Recent findings from an functional magnetic resonance imaging (fMRI) study on language production are also in line with the Inhibitory Control model; during a trilingual switching task, switches to L2 and L3 resulted in increased activity in the right inferior frontal gyrus (rIFG) and the pre-supplementary motor area (pre-SMA),

neural regions related to domain-general inhibition. Engagement of these regions during the use of the weaker L2 and L3 thus point to *ongoing*, active inhibition of L1 (De Bruin et al., 2014).

Studies on language control mechanisms during language perception, however, have been rather sparse. Those that did focus on language perception, often resulted in mixed outcomes regarding switching costs. Some of the few behavioural studies have found symmetric costs, while other studies found no costs at all (Jylkkä et al., 2017; Macizo et al., 2012; Thomas and Allport, 2000; Von Studnitz and Green, 2002).

A possible reason for these divergent findings in comparison to language production is the difference in the very nature of language production versus language perception. While in language production, lexical items need to be actively selected, language perception is mainly based on bottom-up processing. Language control during language perception is therefore less dependent on endogenous control (Peeters et al., 2014).

Also models on bilingual language control during language perception have resulted in different predictions. The Bilingual Interactive Activation Model of Lexical Access (BIMOLA; Grosjean, 1988; Léwy and Grosjean, 2008) has been developed to explain bilingual lexical access during speech perception, and assumes that preceding context in one language can lead to inhibition of words in the other language. Instead, the Bilingual Interactive Activation Plus Model (BIA+; Dijkstra and van Heuven, 2002) proposes that the bilingual lexicon is fully integrated. Language-specific cues thus do not steer the bilingual speaker in a certain language mode, but upon reading words, lexical activation occurs in a purely bottom-up manner. The BIA+ thus differs from its predecessor, the BIA (Dijkstra et al., 1998), which implied top-down regulation of bilingual access, in that sense more similar to the Inhibitory Control model.

#### **1.4.1. The N400(m) as a tool to measure language control in perception**

Various ERP responses have been elicited in response to language switches. Amongst these is the N1 observed at left anterior electrode sites (Proverbio et al., 2004a), the N250 (e.g. Chauncey et al., 2008; Van der Meij et al., 2011), a late

posterior complex (LPC; Moreno et al., 2002; Ng et al., 2014) and the N400 (Proverbio et al., 2004a; Van der Meij et al., 2011; Ruigendijk et al., 2015; for a review on switch effects, see Van Hell and Wittenman, 2009).

The N400 in response to language switches has been taken as evidence of costs at the lexico-semantic level as a consequence of activating lexical forms in the less active language (Van der Meij et al., 2011). The impact of particular switching patterns on the size of the N400, i.e. whether these are symmetrical or asymmetrical, offer a valuable way of assessing various models on language control. Asymmetric switching costs, with a larger N400 for switches to L1 after the use of the (weaker) L2, may thus indicate the reactivation of lexical forms in L1, providing evidence for previous inhibition of L1.

Several studies on language perception have indeed found costs for switches to L1, as measured by the N400 component. For instance, intra-sentential language switches to L1 in written sentences have elicited a larger N400 in L2 learners compared to non-switched words (Van der Meij et al., 2011). The study furthermore showed a modulating effect of proficiency on N400 switching effects. Similarly, a larger N400 was found for L2 learners after switches to L1, in a study using auditory stimuli (Ruigendijk et al., 2015). However, in a sentence reading study, increased N400 responses were elicited in the other switching direction. Namely, switches from the L1 to the L2 resulted in larger N400 effects in simultaneous interpreters, which the authors ascribed to differences in AoA (Proverbio et al., 2004b).

Although a few studies have focused on contrasting language switching in language production and language perception (e.g. Blanco-Elorrieta and Pylkkänen, 2016, 2017), only one has specifically investigated the role of language dominance on cognitive control during language perception. Using the N400m as a measure, this study reported asymmetric switching costs that were in line with models assuming inhibition of the L1 during the use of L2 (Pellikka et al., 2015). The study found that switches to L1 resulted in larger N400m responses in the superior temporal gyrus (STG), bilaterally, indicating effortful reactivation of the previously inhibited L1.

The use of time-sensitive neuroimaging methods may thus be able to reveal subtle differences in language control mechanisms during language perception,

and a suitable way to contrast the control of the various languages of bilingual speakers. Thus, in this PhD thesis, a choice has been made to use such neuroimaging methods in combination with experimental paradigms to investigate language control and semantic processing in native and later-learned languages.

## 2. Aims of the thesis

The aim of this thesis was to investigate the extent to which language control is employed during language perception, and secondly, whether lexical and semantic processing differ for languages that are acquired at an early age or that are learned only after childhood. Of the three studies included in the current thesis, two utilized a language switching paradigm in combination with neuroimaging techniques to investigate control mechanisms while switching between languages (Studies I and II). Study III addressed lexical processing differences using a behavioural lexical decision task.

Thus, each study investigated individuals that were dealing with different types of bilingualism and second-language learning. In Study I, L2 learners of English with varying proficiency levels were compared to English monolingual speakers, whereas Studies II and III focused on early, simultaneous bilingualism (Finnish-Swedish). In Study II, the native languages were contrasted to a later-learned language within the same group, but in Study III, early bilinguals were compared to speakers of the same language who grew up monolingually as well as to late learners.

In Study I, the effects of language switching on semantic processing were investigated in detail. While recording EEG, learners of English were presented with semantically congruent or incongruent sentences in this L2 of theirs. Additionally, congruent and incongruent target words were at times switched to Finnish, their L1. Language switching was predicted to interfere with semantic processes, in case of L1 inhibition during the use of L2. The inhibition of L1 should be especially evident in learners of English with a lower proficiency, for which larger switch costs were thus expected. Alternatively, a switch to L1 could aid L2 learners with a low proficiency to understand the semantic content of the sentence, as their L2 comprehension still relies on links that L2 words have between corresponding L1 representations and the conceptual system.

Study II focused on trilingual language switching in an auditory perception paradigm using MEG. Involvement of control mechanisms was studied for switches between languages that were acquired simultaneously from time of birth and a third language, which was learned at a later age. Hypotheses for this study

were formulated according to predictions made by models on bilingual language processing. In case inhibitory language control takes place during auditory comprehension, we expected to see enhanced N400m responses (switching costs) after switches to early acquired languages from the later-learned English. In contrast, such costs were not expected after switches to English. Switching effects were, however, also expected for switches between the native languages that are particularly strong and therefore can be assumed to require forceful inhibition. If language control is indeed modulated by the strength of a language, in this case expressed by an early AoA, then we should see increased N400m responses when switching from Finnish to Swedish or vice versa.

Study III investigated whether early bilingualism leads to possible disadvantages in the speed and accuracy with which words are recognised, as reported in previous studies. In addition, it addressed the question of whether certain psycholinguistic variables (e.g. frequency) affects the lexical processing of early bilinguals differently as compared to monolinguals, or to late learners of the language. Using a visual lexical decision task in Finnish and in Swedish, reaction times and error rates were measured to different item types: monomorphemic words and pseudowords as well as inflected words and pseudowords. Based on outcomes from previous studies, we hypothesised that we would see larger effects of frequency, morphology and lexicality in the group of early bilinguals, as well as generally slower reaction times and/or accuracy rates. In particular, we tested whether the magnitude of such effects could be predicted by language exposure and other language background characteristics of participants, as predicted by the weaker links account.



### **3. Methods**

#### **3.1. Participants**

All participants were healthy adults between the ages of 18-40. In all Studies, participants gave an informed written consent before participating in the experiment. Participants received compensation for their participation, in the form of cultural vouchers. Participants in Study I and II were all right-handed, had normal hearing, reported no somatic or psychiatric conditions (e.g., major depression) that may have affected cognitive functions, had no diagnosed neurological impairments or language disorders and did not take medication that affected the central nervous system. In Study II, participants reported no history of language disorders, had normal hearing and normal or corrected-to-normal vision, and showed no history of neurological damage. The experimental protocol for Study I and III was approved by University of Helsinki Ethical Review Board in the Humanities and Social and Behavioural Sciences and the experimental protocol for Study II was approved by the Helsinki and Uusimaa Hospital District Ethics Committee.

In Study I, a total of 43 participants took part. Of these, 16 formed a control group of English native speakers, 15 were high-proficient L2 learners of English (CEFR level C2) and 12 had an intermediate proficiency in English (CEFR level B2). Both learner groups were native speakers of Finnish.

In Study II, 18 early balanced Finnish-Swedish bilinguals with high matriculation exam scores in English and a high self-reported proficiency in this language (mean = 5.9, SD = 0.7 on a scale from 1 (elementary proficiency) to 7 (native or bilingual proficiency) participated in the study.

In Study III, a total of 66 participants were tested. These were split up in subgroups of 19 early simultaneous and balanced Finnish-Swedish bilinguals, 19 Finnish native speakers and 28 Swedish native speakers. The latter two groups were raised monolingually before the age of 7, but learned Swedish and Finnish (respectively) at a later age and displayed varying proficiency levels in these two languages.

Table 1 summarises participant information in all Studies.

**Table 1:** Participants in Studies I-III. Prof = Proficiency, Int. = Intermediate.

Study		N	Males	Mean age in years (SD)	English		Finnish		Swedish	
					AoA	Prof.	AoA	Prof.	AoA	Prof.
I	Native English	16	9	32.3 (5.2)	0.0	7.0	21.6	2.6	-	-
	High proficiency	15	6	31.2 (6.3)	8.6	4.0	0.0	7.0	-	-
	Int. proficiency	12	3	32.0 (5.1)	10.6	2.5	0.0	7.0	-	-
II	Early bilinguals	18	8	23.9 (2.9)	9.1	5.9	1.0	6.8	0.2	6.9
III	Early bilinguals	19	7	24.9 (3.6)	-	-	0.2	6.9	0.4	6.8
	Native Finnish	19	4	26.1 (4.6)	-	-	0.0	7.0	11.2	4.8
	Native Swedish	28	9	24.7 (4.7)	-	-	8.2	4.6	0.0	7.0

### 3.2. Questionnaires

In all Studies, participants were asked to fill out extensive background questionnaires. These included questions about the languages they had learned throughout life, their proficiency in these languages as well as the frequency with which they used these languages. In Study II and III, detailed questions about the participant's use of their native language in family situations, school and university were added as well, to gather more information about the degree of balance between the native languages and to ascertain whether a balanced language environment was maintained throughout the life span. For Study II, this information was used to select participants for the experiment, whereas for Study III, the information was coded into language background variables that were later used in the statistical analysis.

Due to the use of neuroimaging techniques in Studies I and II, participants filled out the Edinburgh Handedness Inventory (Oldfield, 1971). This allowed assessment of the degree of right-handedness. In Study III, participants were asked about their handedness via the background questionnaire instead.

### 3.3. Stimuli

In Study I, participants performed a visual sentence reading task in English. Half of the sentences were semantically congruent, whereas the other half continued

in a semantically incongruent manner. The sentences were between 5 and 7 words long and the structure was kept constant using an SVO structure. The target word (noun) always occurred at the position of the direct object. To create sentences containing a language switch, the target word was directly translated into Finnish, or replaced by an equivalent due to contextual or word matching constraints. This resulted in 276 sentences in four versions: a semantically congruent monolingual version, a semantically incongruent monolingual version, a semantically congruent switched version and a semantically incongruent switched version. Target words were matched on word length and Log frequency. Stimulus properties are reported in Table 2.

**Table 2:** Stimulus properties Study I.

	English congruent	English incongruent	Finnish congruent	Finnish incongruent
Log frequency	2.00 (0.5)	1.96 (0.6)	1.96 (0.5)	1.96
Length	5.1 (1.5)	5.0 (1.3)	6.9 (1.5)	6.7 (1.0)

In Study II, stimuli were presented auditorily, in Finnish, Swedish and English. In each language, 486 trials were used, of which 260 non-switched trials, 140 language switch trials (70 for each language direction) and 86 target word trials. The stimuli were monomorphemic nouns referring to animate or inanimate concepts, with a length between 3 and 9 phonemes. Cognates or words that differed in less than two phonemes were excluded. None of the words shared the first three phonemes, to avoid partial activation of phonetically similar words presented later in the experimental sequence. The words were matched for phoneme length and Log frequency. All words were spoken by a female trilingual speaker with no noticeable accent in any of the three languages. Sounds files were normalised and modified with Adobe Audition, including linear fading of the last 10 ms of each stimulus. Equal duration of the words between the three languages was ensured by slightly speeding up the tempo of the Finnish (by 9%) and Swedish (by 5%) words. None of these changes resulted in any pitch changes and were deemed natural by native speakers. Properties of the stimuli used in Study II are presented in Table 3.

**Table 3:** Stimuli properties Study II.

		<b>Log frequency</b>	<b>Number of phonemes</b>	<b>Word duration</b>
<b>Finnish</b>	Non-switch	1.5 (0.5)	4.9 (1.0)	654 (122)
	Swe-Fin switch	1.6 (0.6)	5.1 (1.1)	693 (143)
	Eng-Fin switch	1.6 (0.6)	5.0 (1.0)	653 (114)
	Target word	1.4 (0.6)	5.9 (1.2)	699 (118)
<b>Swedish</b>	Non-switch	1.5 (0.5)	4.8 (1.2)	682 (126)
	Fin-Swe switch	1.5 (0.6)	4.9 (1.2)	680 (120)
	Eng-Swe switch	1.5 (0.5)	4.9 (1.2)	677 (124)
	Target word	1.4 (0.6)	6.0 (1.7)	692 (121)
<b>English</b>	Non-switch	1.5 (0.5)	5.0 (1.8)	678 (116)
	Fin-Eng switch	1.6 (0.5)	5.0 (1.8)	692 (121)
	Swe-Eng switch	1.6 (0.4)	5.2 (1.6)	684 (123)
	Target word	1.4 (0.5)	5.9 (1.5)	683 (117)

In Study III, the participants performed a lexical decision task. Stimuli consisted of Finnish and Swedish monomorphemic and inflected nouns as well as monomorphemic and inflected pseudowords. The pseudowords followed the phonotactical rules of each of the languages and were matched to the length and bigram frequency of the real words in the respective language. In each language, 360 items were used; 80 for each of the item types. Items were matched for letter length, log lemma frequency and log surface frequency. Items varied in length between 4 and 9 letters. A wide range of frequency was included to allow exploration of linear trends in frequency effects. Item properties are summarised in Table 4.

**Table 4:** Stimulus properties Study III.

	<b>Finnish items</b>	<b>Swedish items</b>
<b>Word Length</b>		

MM real	6.13 (1.4, 4-9)	5.61 (1.3, 4-8)
MM pseudo	6.20 (1.4, 4-9)	5.75 (1.1, 4-8)
Infl. real	6.36 (1.3, 4-9)	5.88 (1.1, 4-9)
Infl. pseudo	6.45 (1.3, 4-9)	5.98 (1.0, 4-9)
<b>Lemma freq.</b>		
MM real	3.31 (1.3, 0.74-6.55)	2.16 (1.3, 0.18-6.13)
Infl. real	3.44 (1.3, 0.51-6.47)	2.28 (1.3, 0.32-5.61)
<b>Surface freq.</b>		
MM real	1.57 (1.0, 0.08-4.32)	1.50 (1.1, 0.04-5.49)
Infl. real	1.43 (1.0, 0.04-4.70)	1.45 (1.2, 0.04-4.81)
<b>Cross-L. N. size</b>		
MM real	1.51 (4.5, 0-26)	1.28 (2.8, 0-13)
Infl. real	0.61 (1.6, 0-11)	0.16 (0.5, 0-3)

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### 3.4. Experimental procedures

In Study I, a rapid serial visual presentation paradigm was used, displaying each word for 400 ms with an ISI of 500 ms. Prior to the start of each sentence, a centred fixation cross was displayed. The ITI between sentences was 1000 ms. Participants were instructed to read the sentences carefully, and for comprehension. By using the response pad, they were moreover asked to answer simple yes/no questions that followed 20% of the sentences. The control group of English native speakers was only presented with the monolingual versions of the sentences (138), whereas the other two groups read 276 sentences in total. Lists were constructed so that each version of the sentence only occurred once, to avoid familiarity with the start of the sentence and eventual priming effects. Thus, the sentence *Dan is polishing the shoe* did not occur in the same list as *Dan is polishing the sock* or *Dan is polishing kenkää/sukkaa* (shoe/sock).

In Study II, a rapid auditory switching paradigm was utilised, in which participants were presented with an auditory stimulus every 1600 ms. Participants were instructed to listen carefully to each word, and to press a button each time they heard an animate word (target words). Language switches occurred after three, four or five words were presented in one language. Responses to all six switching directions were obtained in this way. Lists were constructed to introduce variation in the order of the language switches and avoid predictability. Moreover, during list construction, placement of semantically

related words in close proximity was avoided by inserting at least 12 intervening trials.

In Study III, the participants performed a lexical decision task in two languages, as well as the Simon task and the Number-Letter task. Half of the participants started with the Swedish task, whereas the other half started with the Finnish task, after administration of the BAT. Before starting the task in the other language, the participants filled out the BSWQ questionnaire and read through the instructions for the experimental task in the language of the task that would follow. This was done to avoid potential language bias and language interference as much as possible. Participants were instructed to perform the task as quickly, but also as accurately as possible. Each trial started with a fixation cross (500 ms), followed by an item presented for a maximum duration of 2500 ms or until a response was given. The ITI was kept constant at 500 ms.

### **3.5. Data acquisition and analysis**

In Study I, EEG data were recorded with a 64-channel active electrode system (BioSemi, Amsterdam, the Netherlands), with a sampling rate of 512 Hz and a recording bandwidth of DC-104 Hz, in an electrically and magnetically shielded room. The CMS electrode, at the approximate location of PO1, was used as an online reference. External reference electrodes were placed on the mastoids (left and right). Additionally, an electrode was placed below the right eye to capture the vertical electro-oculogram (VEOG). Data analysis was carried out using BESA Research 6.0 software (BESA GmbH, Munich, Germany). The continuous EEG was filtered offline with a bandpass of 0.1–45 Hz. Offline re-referencing of the data was done to the average of the mastoids. Channels (maximum 10%) that were distorted because of technical malfunctioning were replaced by interpolating the data of the surrounding electrode sites (Perrin et al., 1989; Bendixen et al., 2008). Using a principal component analysis, automatic eye-blink correction was performed on the data (PCA; Ille et al., 2002). Other remaining artefacts were automatically removed by using a  $\pm 100$   $\mu$ V rejection level. After artefact correction, 12% of the trials were excluded on average. The length of the EEG epoch spanned 200 ms before and 900 ms after stimulus onset,

with a baseline correction of -200 to 0 ms. Epochs were averaged separately for each condition.

MEG data in Study II, were recorded with a 306-sensor Elekta Neuromag neuromagnetometer (Elekta Ltd., Helsinki, Finland), using a 600-Hz sampling rate and a 0.03–200 Hz bandpass filter. The MEG device had 102 sensor elements with two planar gradiometers 25 and one magnetometer. Vertical and horizontal electro-oculograms (EOG) were recorded simultaneously. Prior to data acquisition, the location of HPI coils were obtained by means of a 3D digitiser (Fastrak, Polhemus, Colchester, VT, USA). Continuous raw MEG data were preprocessed and cleaned with tSSS (MaxFilter™ software). Data were filtered offline with a 0.01–45 Hz frequency band. Further data analyses were done with BESA Research 6.0 Software (BESA GmbH, Munich, Germany). Ocular movement artefacts were removed with PCA, using 5000 fT/cm limit for gradiometers. For source reconstruction, a BESA built-in 4-shell standard spherical head model was used, and all 204 gradiometers were utilised. This was done to reduce subjectivity related to sensor selection (Pylkkänen et al., 2006). Dipole modelling using ECD (Hämäläinen et al., 1993; Salmelin, 2010) was done in conjunction with LORETA distributed source analysis.

Behavioural data from the lexical decision task in Study III, were preprocessed by excluding reaction times more than 3 SD above or below the participant's mean. In total, this led to excluding 8.2% of the Finnish data and 10.7% of the Swedish data. Also items that were responded to incorrectly by at least 45% of the language-dominant speakers were excluded from further analysis.

### **3.6. Statistical analysis**

ANOVAs were performed to analyse the data in Studies I and II. In Study I, mean amplitudes were calculated for each participant in each condition for ROIs showing the most prominent response in time windows around each ERP component. Monolingual data were analysed with a four-way mixed model ANOVA, using between-subjects factor Group (three levels) and factors Congruency (two levels: congruent/incongruent), Hemisphere (HS, three levels: left, midline, right), and Anterior–Posterior division (AP, three levels: anterior,

central, and posterior). To test modulation of the N400 during language switches in both L2 groups, the ANOVA further included the factor Switch (two levels: switch / no switch). ANOVAs were also performed on switched and non-switched stimuli using different ROIs and time windows.

In Study II, a repeated-measures ANOVA (Switch x Hemisphere) was used to analyse differences between all switched and non-switched stimuli for using average strength of the N400m and the earlier frontal response for each participant and each condition. To analyse non-switched stimuli only, an ANOVA (Language x HS) was performed. Differences between language switching directions were thereafter analysed with an ANOVA (Base language x Target language x HS). In Studies I and II, statistical analyses were performed with SPSS Statistics 24 Software (IBM Corp., Armonk, NY, United States). Greenhouse-Geisser corrections were applied wherever appropriate and in the results, *p*-values after correction are reported. Bonferroni corrections were applied to *Post hoc* analyses.

In Study III, behavioural data were analysed using linear-mixed models. To normalise their distribution, reaction times were log-transformed (base 10) prior to subjecting them to analysis. Further visual inspection of residual plots did not reveal obvious deviations from normality or homoscedasticity. Random intercepts for Subject and Item (crossed random effects models; see Carson & Beeson, 2013) were included in all linear mixed models of RTs and error rates. Group differences and their interactions with psycholinguistic factors were analysed for Finnish and Swedish separately, for the Full dataset (all items), Real word data (only monomorphemic and inflected real words) or Word and Pseudoword data (only monomorphemic real words and pseudowords). Group, Lexicality, Morphology, Word Length and all first-order interactions were entered as predictors where appropriate. Final models were built using the step-wise method for model selection. Within-group analysis of continuous language background variables was done for each of the three groups and each language separately, in the same three datasets. Here, the following fixed factors were entered as predictors: Objective Language Proficiency (continuous), Self-Reported Language Proficiency (continuous), Age of Acquisition (continuous), Active Use of Language (continuous), Passive Use of Language (continuous),

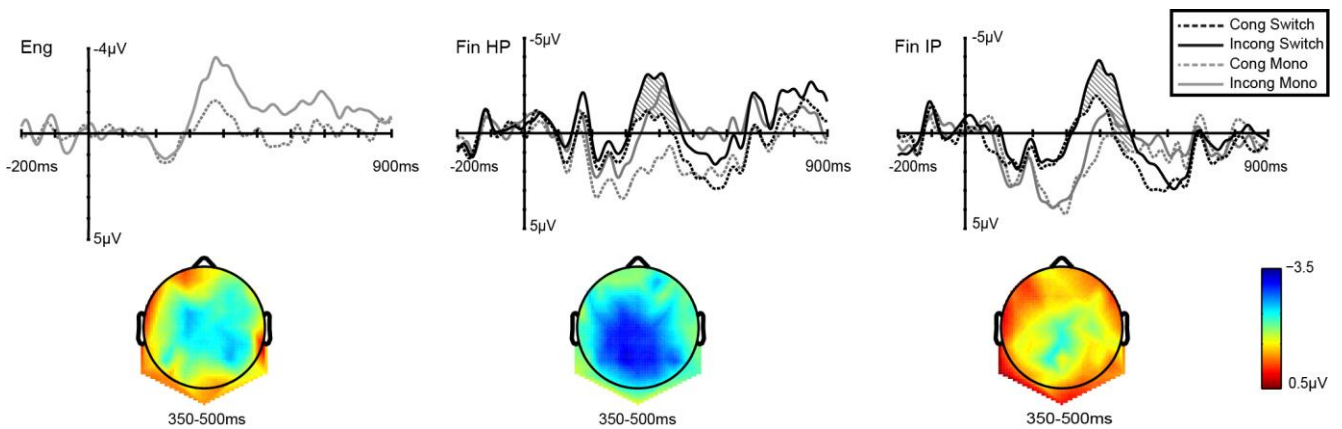


Active and Passive use of Language (continuous) and Cross-Language Neighborhood Size (continuous), as well as their interactions with all psycholinguistic factors. In case of collinearity, the variable with the least explanatory power was residualised, following the method by Newman et al. (2012). Linear mixed-effect analyses for Study III were performed in R, version 3.3.1 (R Core Team, 2016). The lme4-package was used to fit all models (Bates et al., 2015).

## 4. Results and Discussion

### 4.1. Study I: The effect of switches to L1 during semantically congruent and incongruent sentences

Study I set out to investigate whether semantic processing is affected by language switches to L1 (Finnish), when sentences are read in L2 (English), and furthermore to study the modulating effect of language proficiency. We hypothesised that incongruent target words in monolingual English sentences would yield a similar semantic N400 effect in high-proficient L2 speakers, compared to a control group of native English speakers. In L2 speakers with an intermediate proficiency we expected a smaller effect than seen in native speakers. Switched target words, however, were predicted to interfere with semantic processing due to L1 inhibition during the use of L2 and switch-related N400 activity.



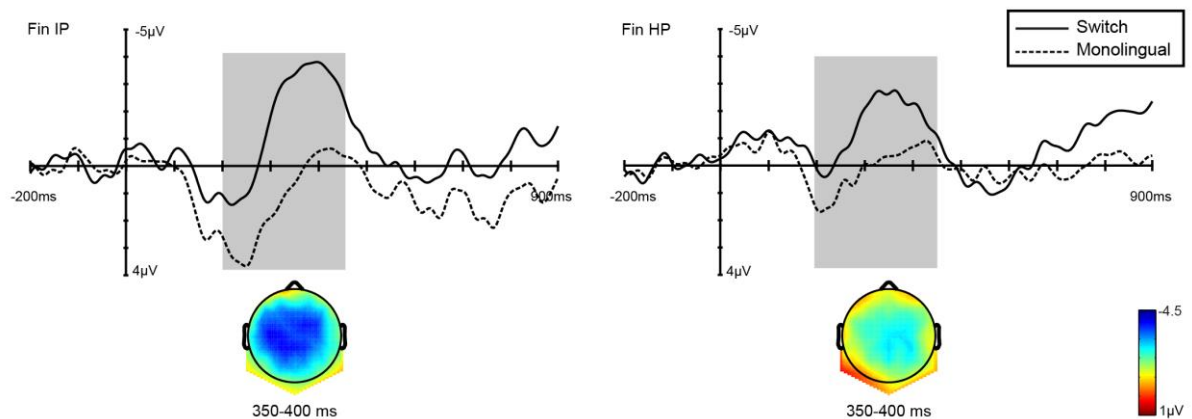
**Figure 1.** Grand-average waveforms taken from a region of interest (ROI) that consisted of a set of nine centro-parietal electrodes. Each of the four conditions is plotted for the two L2 learner groups (Fin IP = Finnish speakers with intermediate proficiency in L2, Fin HP = Finnish speakers with high proficiency in L2), while for the English native speakers (Eng) responses to congruent and incongruent monolingual items is illustrated. The shaded region depict the semantic N400 effect that was found during switched items (difference between congruent and incongruent words). Accompanying scalp maps were obtained for the 350–500 ms time windows for the averaged values of difference waves (language-switched incongruent minus language-switched congruent), for the English native speakers the scalp maps for the monolingual items (incongruent minus congruent words) is displayed. The X-axis represents time in ms: the 200 ms baseline is plotted, time 0 coincides with the onset of the target word. The Y-axis represents amplitude (microvolts).

Incongruent target words elicited a typical N400 effect (e.g. Kutas & Hillyard, 1983). However, no significant differences between the three groups in the size of the semantic N400 in the monolingual sentences were found, even if the N400 effect seemed visibly smaller in the intermediate proficiency group (See Figure 1). Details of the statistical results are reported in Table 5.

**Table 5:** ANOVA results of the main effects of interest in Study I, for early (N250; 200 – 300 ms and switch-specific N400; 300–450 ms) and late switching effects (LPC; 520–670 ms) as well as congruency effects (Semantic (Sem.) N400 for monolingual and switched stimuli; 350–500 ms).

Main effects	ANOVA results		
	F	df	p
N250 <i>Switch</i>	34.16	1, 26	< .001
Sem. N400 – monolingual <i>Congruency</i>	27.64	1, 41	< .001
Sem. N400 – switched <i>Congruency</i>	23.14	1, 26	< .001
Switch-specific N400 <i>Switch</i>	37.83	1, 26	< .001
LPC <i>Switch</i>	4.34	1, 26	< .05

Moreover, switches to L1 did not seem to interfere with semantic processing, as the semantic N400 effect remained significant when comparing congruent and incongruent sentence continuations and did also not significantly differ in amplitude compared to the semantic N400 effect in monolingual sentences (see Figure 1). Importantly, switches resulted in a switch-related N400, which was characterised by an earlier onset and slightly different topography compared to the semantic N400 (see Figure 2). Switches furthermore resulted in a fronto-centrally distributed early negative deflection in the 200-300 ms time window (N250) and in a parietally distributed LPC in the 520-670 ms time window, showing more positive mean amplitudes for switches than for English target words.



**Figure 2.** Grand-average waveforms from a ROI of nine fronto-central electrodes, that represented the language switching effects. Congruent and incongruent switched and non-switched stimuli were averaged and plotted for both L2 learner groups (Fin IP = Finnish speakers with intermediate proficiency in L2, Fin HP = Finnish speakers with high proficiency in L2). Scalp maps reflect the averaged values of difference waves (language-switched minus non-switched). The X-axis represents time in milliseconds: the 200 ms baseline is plotted, and time 0 marks the onset of the visual stimulus. The Y-axis represents amplitude (microvolts).

Language proficiency was therefore concluded not to have an impact on semantic processing in this study, as both groups of L2 learners showed native-like responses as compared to English native speakers. These results are in line with predictions made by the convergence hypothesis (Green, 2003). Previous research often found the semantic N400 to be smaller or delayed in L2 learners (Ardal et al., 1999; Newman et al., 2012), but participants in these studies often displayed a lower language proficiency level than the levels that our current participants had attained. This could also explain why the L2 learner groups did not differ in their response to language switches, i.e. the mental cost that occurred after encountering a switch.

The switch-specific N400 and semantic N400 seemed to be two distinct components based on their latency and scalp distribution, which suggests these to stem from at least partially different neural mechanisms. The switch-specific N400 may reflect increased mental effort, and has previously been associated with language control and prior language inhibition (e.g. Pellikka et al., 2015). In the current study, though, a switch in language did not prevent the discrimination between semantically congruent and incongruent target words, rendering involvement of language inhibition improbable in this case, or at least, showing that reactivation of words can occur almost instantly. Language switching may

therefore not necessarily be costly for the comprehension of semantic content. Executive control processes related to task switching or language control could occur in parallel with semantic processing.

## 4.2. Language control mechanisms during language switching in trilinguals

The main goal of Study II was to investigate the effect on AoA on language control mechanisms during auditory processing. A language switching paradigm was therefore utilised, involving rapid switching between three languages: Finnish, Swedish and English, while recording online MEG responses. The participants in this study were early, simultaneous Finnish-Swedish bilinguals that used both languages to a roughly equal extent throughout their lives, whereas English was learned only after early childhood. The participants did not display significant differences in their language proficiency levels between the three languages. An overview of all statistical results can be found in Table 6.

**Table 5:** ANOVA results of the main effects of interest in Study II, for N400m responses in the STG (400-600 ms) and IFG responses (350-450 ms).

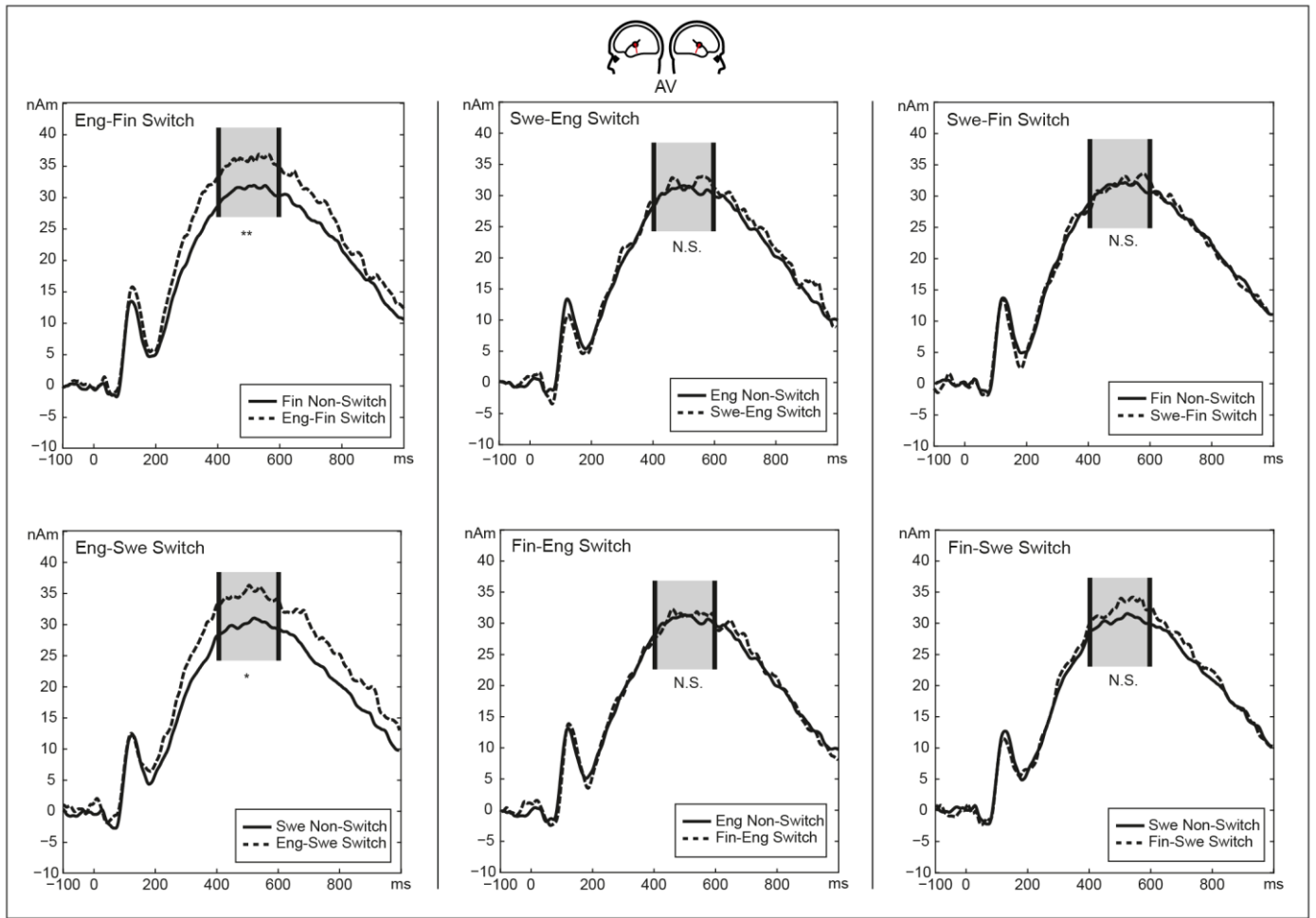
Main effects	ANOVA results		
	F	df	p
Switches vs. non-switches			
<b>STG</b> <i>Switch</i>	13.29	1, 17	< .01
<b>IFG</b> <i>Switch</i>	13.29	1, 17	< .05
Non-switches			
<b>IFG</b> <i>Language</i>	6.82	2, 34	< .05
Switch directions			
<b>STG</b> <i>Base x Target</i>	8.30	4, 68	< .001
<b>Post Hoc:</b>			
<i>Eng-Fin vs. Fin non-switch</i>			< .05
<i>Eng-Swe vs. Swe non-switch</i>			< .01

We found increased N400m responses for switches from the later-learned English to either of the native languages compared to non-switches, which was expected because of the assumedly preceding language inhibition of the native languages. The N400m responses were localised in the Superior Temporal Gyrus (STG). As predicted, these switching costs did not occur after switches from the native languages to English, demonstrating a classic pattern of asymmetric switching costs, in line with an earlier MEG study on language switching in the auditory modality (Pellikka et al., 2015). Our results furthermore showed increased source strength in the inferior frontal gyrus (IFG) for English non-switches compared to non-switches in Finnish and Swedish, which could be taken as evidence for ongoing inhibition of the native language during the use of English. The IFG has been associated with language control in several other studies (Abutalebi et al., 2007; Venkatraman et al., 2006; Hosoda et al., 2012; Stein et al., 2009).

The asymmetric switch cost pattern observed in our switching paradigm has not always been found in behavioural studies (Macizo et al., 2012; Thomas and Allport, 2000; Von Studnitz and Green, 2002). Possibly, neuroimaging techniques are more sensitive to capture small differences in language control processes. In EEG, for example, switches to L1 have also frequently yielded increased N400 responses (e.g. Van der Meij et al., 2011; Ruigendijk et al., 2015).

Unexpectedly, however, switches between the early acquired native languages, did not result in any switching costs at all. N400m responses were not significantly different compared to non-switched words in Finnish or in Swedish. Figure 3 illustrates the asymmetric switching costs as well as the absence of costs in early native languages.

We thus interpreted these results as evidence that language control mechanisms for early acquired languages are different from those that are employed when a later-learned language is used. Possibly, responses to switches to the second native language are not costly because language switching between these early languages has become more or less automatised, and/or has led to more effective language control between these languages.



**Figure 3.** Mean strength of the N400m activation (across left and right hemispheres) for all six switching directions; switched words are always compared to non-switched versions. The shaded areas indicate the region tested for statistically significant differences. One asterisk indicates  $p < 0.05$ , two asterisks indicate  $p < 0.01$ .

Whether the difference in language control mechanisms is ultimately due to the AoA or due to the frequency of language use cannot be completely resolved, while both factors differed between the early languages and the later-learned English. A recent fMRI study stressed the importance of language exposure on language control mechanisms, showing that even a month of language exposure can lead to changes in the way languages are controlled (Tu et al., 2015). AoA has nevertheless been shown to affect language processing in profound ways (for a review, see DeKeyser, 2005), so possibly even a mix of recent language exposure as well as the use of a language over the life span could contribute to the strength of the language network.

### 4.3. Study III: Speed and accuracy of word recognition in early bilinguals and late learners compared to monolinguals

In Study III, the main goal was to investigate the putative bilingual disadvantage related to word recognition. In addition, the goal was to see where eventual disadvantages would stem from, i.e. whether they are mostly due to less exposure to each of a bilingual's languages or to increased competition between words in the bilingual lexicon.

To answer these questions, a lexical decision task was set up in the two languages of the early bilinguals that we tested: Finnish and Swedish. Four different item types were used in the task: monomorphemic words and pseudowords as well as inflected words and pseudowords. The lexical decision tasks were also performed by monolingually raised speakers in each of the languages, who at the same time served as late learners of the other language.

**Table 5:** Overview of significant effects from Linear Mixed Models performed on the Finnish and Swedish datasets, reporting the effects where early bilinguals showed larger effects or worse performance. In case of Group effects or interactions, estimations are reported for early bilinguals (BIL), Finnish-dominant speakers (FIN) or Swedish-dominant speakers (SWE) based on comparisons with monolingually-raised speakers.

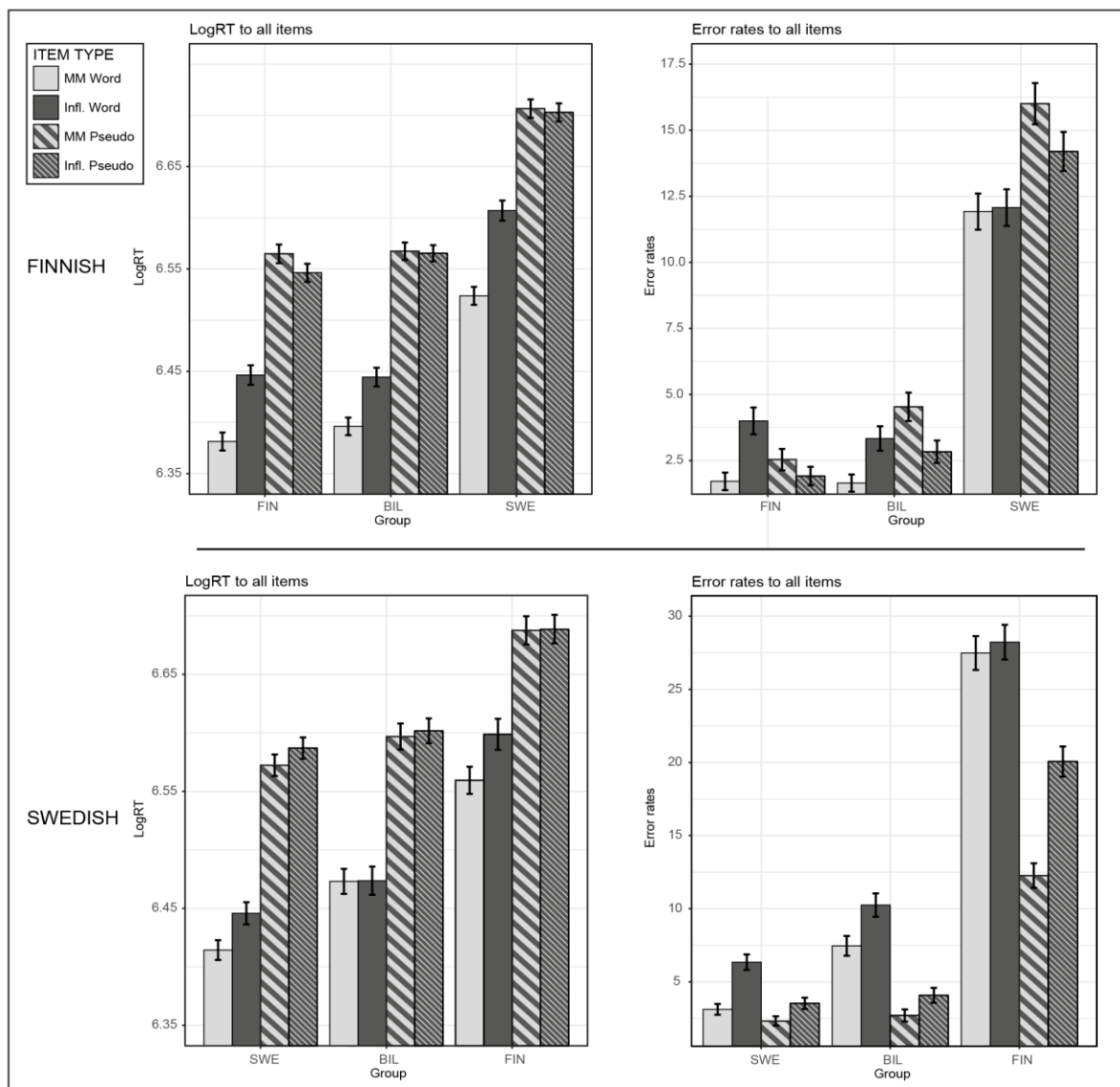
Significant effects		$\beta$	t	p
<b>Finnish full dataset</b> <i>Error rates</i>	Group x Lexicality	BIL: 1.82	2.10	< .05
		SWE: 3.73	4.70	< .001
<b>Finnish real word data</b> <i>LogRT</i>	Group x Frequency	BIL: -0.008	-1.95	.051
		SWE: -.023	-5.55	< .001
<b>Swedish real word data</b> <i>Error rates</i>	Group x Frequency	BIL: -2.22	-3.76	< .001
		FIN: -7.23	-12.19	< .001
<b>Swedish mono-morphemic words and pseudowords</b> <i>Error rates</i>	Group	BIL: 8.23	2.52	< .05
		FIN: 37.57	11.48	< .001

Surprisingly, the responses of the early bilinguals were not any slower than those of the monolingually raised speakers, neither in Finnish or in Swedish. Only in one of the six data sets in Swedish, a significantly lower accuracy rate was revealed. Second-language learners, however, showed longer reaction times and lower accuracy rates throughout both lexical decision tasks. Figure 4 illustrates the data from each of the three groups for each of the four item types in Finnish



and in Swedish. An overview of statistical results where differences were found to be larger for early bilinguals, is presented in Table 7.

Regarding the size of effects for each of the psycholinguistic variables, the early bilinguals only showed a larger lexicity effect in one of the three datasets in Finnish, and larger frequency effects in Finnish and Swedish. Even for L2 learners, no larger effects for morphology were found. The larger frequency effects in Finnish and Swedish, were moreover mainly associated with a less active use of the languages. Competition between words of each language did not affect the size of the frequency effect, nor that of lexicity.



**Figure 4.** Reaction times and accuracy rates to all item types in Finnish and Swedish, for each of the three groups (Finnish monolingually raised speakers (FIN), early bilinguals (BIL) and Swedish-monolingually raised speakers (SWE)).

The results of this study are to some extent in contrast with some of the previous studies on the bilingual disadvantage. Some studies on language production, for instance, found increased reaction times, even if the task was performed in the dominant language (Gollan et al., 2011). Previous studies on visual word recognition combining behavioural data with ERP data, also found slower and less accurate responses as well as larger effects of morphology, lexicality and frequency (Lehtonen et al, 2006; Lehtonen et al, 2008; Lehtonen et al, 2011).

Our study thus only replicated the larger frequency effect that has been found by (early) bilinguals and L2 learners alike (Lehtonen et al, 2006; Lehtonen et al, 2011; Kroll et al., 2002; Ellis, 2002), which was mostly explained by the active use of the languages. Compared to monolingually raised speakers, the frequency of use of both of the languages was lower. However, less exposure to the language over the life span did not majorly affect the general speed or accuracy of lexical decision in early bilinguals. These results are promising for early bilinguals, showing that a balanced use of both languages throughout life may not lead to a worse performance compared to people who grew up using only one language.

## **5. General discussion**

The studies in the current thesis focused on investigating how early acquired and later-learned languages are processed (Study I, Study III) and controlled (Study I, Study II), and what role several language background factors play in this matter, including factors such as age of acquisition, language use and language proficiency. The main findings of these studies were:

- 1) An intermediate proficiency in L2 is enough for L2 learners to show similar ERP responses to semantic content compared to native speakers (Study I);
- 2) Language switches to L1 do not interfere with ongoing semantic processes, as ERP responses still show sensitivity to differences in semantic congruency (Study I);
- 3) Control mechanisms for early acquired native languages differ from those of a later-learned language likely due to lifelong experience with switching between these languages (Study II);
- 4) Inhibition of native language(s) occurs even when an L2 is only perceived visually or auditorily (Study I and II);
- 5) Growing up in a bilingual environment does not necessarily lead to notable disadvantages in word recognition processes, at least when the languages are used in a very balanced manner (Study III).

### **5.1. Semantic and lexical processing in L1 vs. L2**

One of the aims of the current thesis was to investigate second language processing in the lexical-semantic domain during language perception, and compare this to the performance of native speakers.

Although some early theories on language processing are based on the notion of a ‘critical period’ for language acquisition (Lenneberg, 1967), studies have shown that while grammar is hard to learn for L2 speakers (e.g. Ullman, 2001; 2004), native-like processing is possible in the domain of semantic and lexical processing (Kotz, 2001). Evidence from fMRI studies have furthermore shown that the same underlying neural structures may eventually be used, when the proficiency in L2 is high enough (Abutalebi, 2001). This is in line with the

‘convergence’ hypothesis, which implies that the representation and processing of the L2 can be similar to that of native speakers of the language, as the proficiency in L2 increases (Green, 2003).

Results of the studies in this thesis further confirmed that at least on the ERP and ERF level, the way semantic information is processed can be similar to native speakers. In Study I, the amplitude of the N400 effect in response to semantically incongruent target words did not significantly differ between the three experimental groups (English native speakers and L2 speakers with an intermediate or high L2 proficiency). The N400 effect in L2 speakers with a lower proficiency has previously been found to be delayed and/or reduced in amplitude compared to native speakers (e.g. Ardal et al., 1999; Newman et al., 2012). However, likely due to the relatively high proficiency of the participants in Study I, the lexical representations in the L2 lexicon are strong enough for them to perceive the difference in semantic fit in a similar way as native speakers. An intermediate language proficiency may thus be enough to develop sufficiently strong connections between lexical representations and the mental concepts these entail, fitting with the later stages of L2 learning as described in the RHM model (Kroll & Stewart, 1994).

Although Study II used the auditory modality, the Finnish-Swedish early bilinguals did not display any difference in the strength of N400m to non-switched words in Finnish, Swedish or English, the results thus corroborating the convergence hypothesis and the RHM model. Arguably, this could mean that their high proficiency in English was thus sufficient to develop similar overall baseline activation levels in English compared to their native languages Finnish and Swedish. The design of the study does not allow to form any concrete predictions on the exact proficiency level needed to reach such comparable base activation levels of words in L2. In future studies, by comparing different groups of varying proficiency, this matter may be elucidated.

Behavioural results in Study III indicated that the performance of L2 learners of Finnish and Swedish, compared to monolingually raised native speakers did not reach native-like levels. Instead, reaction times in the lexical decision task were longer and more errors were made throughout the datasets. These results can be partly explained by the wide range of proficiency levels describing these

L2 learners, purposefully set up this way, to allow analysis using linear-mixed models. The average proficiency level was therefore considerably lower compared to native speakers, unlike in the other Studies of the present thesis. Moreover, due to the use of alternative proficiency level scales, direct comparisons with the performance of L2 learners in Studies I and II can therefore not be made. Secondly, the task included many words in the low frequency range, which could also explain the slower average responses in L2 learners, who are still developing their L2 lexicon. Many studies on lexical decision have described a similarly slower and less accurate performance of L2 learners, but have also suggested better performance as proficiency and frequency levels increase (e.g. Harrington, 2006), or with an expanding vocabulary size (Diependaele et al., 2013).

The bilingual disadvantage (e.g. Gollan et al., 2008) is not focused on differences in L2 performance, but nevertheless, the change in L1 performance as a result of being (an early) bilingual, is a related topic and offers valuable information on the lexical organisation in bilinguals. In Study III, convincing evidence for a bilingual disadvantage was not found. Only the frequency effect was larger for early bilinguals in both of their native languages, and the size of this effect was found to be associated with the frequency of use of that particular language, which provides support for the weaker links hypothesis (e.g. Gollan & Silverberg, 2001; Gollan et al., 2008). The effect of language exposure on the frequency effect has been demonstrated before in computational simulations as well (Monaghan et al., 2017). Furthermore, no evidence was found to support the competition account of the bilingual disadvantage. The results of Study III make an important contribution to knowledge on bilingual processing in early bilinguals, and show that growing up bilingually does not necessarily have to be paired with impoverished language performance, at least in word recognition. Future studies may attempt to address the impact of language exposure and active language use on performance in language production as well.

Taken together, native-like processing of lexical and semantic information in L2 is possible, after a high enough proficiency in L2 has been reached, or when L2 learners have received sufficient exposure to the language. Unlike described in the convergence hypothesis (Green, 2003), the results of this thesis show that language proficiency is not the only factor contributing to the strength of the

language network. The strength of the language network may in fact be due to an interplay of many background factors, not limited to what was found in this thesis. On the neural level, such a view would be compatible with the cell assembly - or Hebbian – theory (Hebb, 1949): any manner in which underlying neural representations of language could be strengthened, would be beneficial to the processing thereof.

Language proficiency is ultimately highly intertwined with language exposure (Abutalebi et al., 2001); the more exposure one receives, the higher one's proficiency level usually is too. Although some studies have deliberately attempted to separate these language background factors, the effects of proficiency and language exposure may have been partly confounded in the studies of the current thesis, at least in Studies I and II.

## **5.2 Control mechanisms for native and later-learned languages**

The second main topic of the current thesis evolved around the way native and later-learned languages are controlled. Various models have attempted to explain the management of more than one language, especially when only one of the languages is in use. Models such as the 1) Inhibitory Control model (Green, 2003), developed to explain bilingual language production; 2) the BIMOLA (Grosjean, 1988; Léwy and Grosjean, 2008), focused on auditory perception of languages and 3) the BIA (Dijkstra et al., 1998)) on visual word recognition, are all based on the notion that language interference from the non-target language is mostly managed via inhibitory influences and top-down regulation. On the other hand, other psycholinguistic models such as the BIA+ (Dijkstra and van Heuven, 2002), the follow-up model of the BIA, are attempting to take language non-selectivity into account and does not assume that lexical representations of one language would be suppressed in a context of another language.

In Study I, significant switch costs after switches to L1 were encountered, as measured by N400 responses. This could potentially point to previous inhibition of the native language, after reading sentences in L2, and consequential reactivation of representations in L1. Yet, switches in the other direction were not measured, making it challenging to make any final interpretations about what

this switch cost precisely reflects. The study design, combining switches with manipulations of semantic incongruency, nevertheless allowed us to investigate the effect of language switches on semantic processing. The results of Study I indicated that switches to L1 did not have an adverse effect on the ability to discriminate between semantically congruent and incongruent words in this language, which might have been expected in case the language was inhibited. Instead, even though an unexpected language switch takes place, L2 learners are still able to integrate the target words within the previous context, demonstrating a flexible adaption to changing language environments. Semantic processing and executive control processes related to switching between tasks schemas related to each language (Dijkstra and Van Heuven, 2002), can, possibly, occur in parallel.

Furthermore, similar to the findings on the absence of a modulating effect of proficiency on semantic processing in L2, results of Study I did not show significant effects of proficiency on any of the switch costs (N250, N400 and LPC), even if such prior studies have been found such modulations (e.g. Ruigendijk et al., 2015; Moreno et al., 2002 & Van der Meij et al., 2011). Again, it may be that intermediate language proficiency was sufficient to employ similar control mechanisms as participants with a high proficiency did, resulting in similar responses to switches in both L2 learner groups, at least on the ERP level.

Results of Study II, however, clearly fit with predictions made by models that assume inhibition of the native language during the use of L2. Asymmetric switch costs, reflected by larger N400m source activation (STG), were found when comparing switches from the later-learned English to either of the native language to the other switching direction. It could be argued that not inhibitory control, but instead persisting activation of L2 could explain these asymmetric costs (Philipp et al., 2007). Based on absent increased activation after switching to English, and similar baseline levels for this language as compared to the native languages, such persisting additional activation of English is not likely. Involvement of the IFG during the use of English further provides evidence for inhibitory control, as the IFG has been previously found in studies on language control (e.g. Venkatraman et al., 2006), and is suggested to be part of the cognitive control network (Miller and Cohen, 2001).

The results of Study II add to previous MEG findings on asymmetric switch costs and proposed language inhibition during auditory perception (Pellikka et al., 2015). While previous behavioural studies on language perception resulted in symmetric or an absence of switch costs (Macizo et al., 2012; Thomas and Allport, 2000; Von Studnitz and Green, 2002), the results of the current thesis point to possible involvement on language inhibition during language perception. Possibly, the high temporal sensitivity of electrophysiological techniques enables capturing subtle changes during ongoing language processing that might be missed by behavioural methods (Rivera-Gaxiola et al. 2005). Furthermore, language control in the auditory vs. the visual domain may differ substantially. Visually presented words facilitate instant word recognition (Grainger & Holcomb, 2009) whereas auditory presentation result in temporal unfolding of the speech signal. This could activate alternatives that share overlapping phonological features, which in turn have to compete for activation (Dahan et al., 2001).

Following the logic of active competing alternatives, inhibitory processes should be particularly apparent when switching between native languages. Gollan and Ferreira (2009) also hypothesised that bilinguals with a high proficiency may apply equal inhibition to both languages. Yet, the most striking finding in Study II was the absence of switch costs when switching between native languages, which was unexpected based on models assuming language inhibition. These results are the first of its kind using MEG, implying that AoA might play a large role in the way languages are controlled, with language exposure throughout the life span leading to possible automatization of language switching. More experience in an L2 has been previously shown to lead to smaller LPC switch costs in bilinguals (Moreno et al., 2002), as switches are perceived as less unexpected or less difficult to process, which offers support on the view of automatization in language switching. Another interpretation of the results in Study II may be that instead of AoA, the *current* use of the languages on a weekly basis plays a large role in reducing switch costs. The current use of languages also differed between the native languages (both ~40%) on the one hand, and the later-learned English (~20%) on the other. A recent study has shown the impact of recent language exposure on control mechanisms (Tu et al., 2015), rendering an investigation of



a possible interplay between AoA and language use an interesting topic for future studies, for example by controlling for the recent language exposure, or investigating it as a continuous variable. The effects of AoA on the cerebral representation of language may be overcome by proficiency and language exposure (Abutalebi et al., 2001), but so far it has not been clearly shown whether AoA also affects the way these languages are controlled. Via lifelong exposure, AoA could have a great impact on language control. Study II showed no increase of IFG activation while switching between native languages. Decrease of left prefrontal activity indicates less dependence on controlled processing (Perani et al., 2003), pointing to the impact of an early AoA or lifelong language exposure on long-term cognitive plasticity. Prefrontal neural structures are furthermore specifically engaged during the use of a language with lower amounts of lifelong exposure (Abutalebi et al., 2007).

Our results on language control contribute to the field of bilingualism by showing that 1) switch costs are encountered when switching languages in both the visual and the auditory domain 2) although switches to L1 result are costly, these do not interfere with ongoing semantic processes in sentence reading and 3) the control of early acquired native languages differs from that of a later-learned language.

### **5.3 Limitations and future directions**

Some limitations of the Studies are worth discussing. The lower sample size in the intermediate proficiency group in Study I may have led to less statistical power in this particular group than in the other ones. In case a larger group could have been investigated, the differences in the size of the N400 effect to semantic incongruities might have become significant compared to the other two experimental groups. Future studies employing a cross-sectional design may thus benefit from using larger sample size. Interesting comparisons may furthermore be made when an even larger range of proficiency levels is considered, allowing to track development of semantic processing in an elegant way.

Some of the language background factors in Studies I and II may have correlated with one another to some extent. In Study I, the set up intended to

compare groups with different proficiency levels, but consequently, AoA was found to slightly differ as well. Even though our correlation analyses did not show a significant impact of AoA, future studies may attempt to include even more stringent recruitment criteria. Also in Study II, the native languages of the early bilinguals differed from the later-learned English in amount of language use, besides the targeted difference in AoA. To replicate findings on control mechanisms in early native languages, an improved set-up could eliminate such differences. This could further add to knowledge on the precise role of AoA in mechanisms of language control.

Finally, one of the limitations in Study III has been the measurement of Swedish monolingually raised speakers that grew up in Finland, instead of Sweden. Due to environmental factors that could not be controlled, the implicit exposure to Finnish in daily life could have impacted the way the native Swedish was processed in this group, thus possibly diminishing differences to the other groups. Testing ‘pure’ monolinguals is in this case preferable, although truly ‘pure’ monolinguals can hardly be found in today’s global world. However, an attempt to find participants that have had limited exposure to another language is preferred in experiments that aim to test differences between monolinguals and bilinguals.

## 6. Conclusions

The present thesis investigated lexical and semantic processing in L1 and L2 as well as language control mechanisms of bilinguals, and how they may be affected by whether an additional language has been acquired early in life or learned only after childhood. The results demonstrated that native-like L2 processing is possible in the semantic domain. As long as language exposure and language proficiency are sufficient, the L2 learner may show performance similar to native speakers of that language. Effects of AoA in semantic processing may therefore be surpassed by the development of high proficiency and a frequent language use, factors that a late learner is able to actively develop or personally influence.

In some cases, however, when L2 learners have received less exposure or do not yet fully master the language, larger frequency and lexicality effects can be observed in word recognition, and such differences may be seen even in early bilinguals. Early bilinguals, however, perform on par with monolingually raised counterparts in general speed and accuracy of word recognition, if they have received sufficient language exposure and used both languages to an equal extent throughout their life.

Yet, the control mechanisms involved in switching between the native languages of early bilinguals seem to differ compared to the mechanisms needed to control the use of a later-learned language. While inhibition of the native languages is needed during the use of a later-learned language, to prevent their distracting influence, the early-acquired native languages do not seem to be controlled by the same inhibitory mechanisms. This could be due to lifelong experience of switching between the languages, leading to more automatic and less effortful switching. This thesis showed that AoA likely impacts the language control mechanisms that are at play in environments where more than one language is used.

Lastly, the current findings in the visual modality showed that switch costs are rather large, but do not interfere with semantic processes. The bilingual brain registers changes in its language environment quickly, and seems to adapt accordingly. Overall, bilingual speakers seem to seamlessly integrate linguistic stimuli from more than one language to create a meaningful whole. Hence,

bilinguals are likely using their full linguistic knowledge to make sense of the linguistic input around them, while at the same time being constantly aware of language membership.

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## ORIGINAL RESEARCH ARTICLES